9-2

WD

June 24, 1991

WD

Mr. J. William McDonald
U.S. Bureau of Reclamation
Denver Office
P.O. Box 25007
Denver, CO 80225-0007

Dear Mr. McDonald:

Subject: Irrigation and Drainage Decision Support System
(Irrigation Drainage)

Imperial Irrigation District (IID) has a keen interest in determining ways to improve the efficiency of its water use. Accordingly, we would like to explore the possibility of joint funding of irrigation and drainage research work as proposed in your June 4, 1991, letter.

At this preliminary stage, it would be helpful if Colorado State University would develop a draft proposal that would define the objectives, time frame, and expected cost for the study. IID staff would be available to work with Dr. Garcia and Dr. Podmore to help formulate the proposal.

Very truly yours,

Robert A. McGillough

for CHARLES L. SHREVES
General Manager

RJL:clc
a:I&Dsup.sys

United States Department of the Interior

TAKE PRIDE IN AMERICA

BUREAU OF RECLAMATION
DENVER OFFICE
P O BOX 25007
BUILDING 67, DENVER FEDERAL CENTER
DENVER, COLORADO 80225-0007

IN REPLY REFER TO:

D-5740

JUN 4 1991

Mr. Charles L. Shreves
General Manager
Imperial Irrigation District
PO Box 937
Imperial CA 92251

Subject: Irrigation and Drainage Decision Support System (Irrigation Drainage)

Dear Mr. Shreves:

The Bureau of Reclamation (Reclamation) has been interested in integrating an irrigation scheduling module with consumptive use and drainage modules into a single decision support system. Dr. Luis Garcia has begun work on the drainage and consumptive use modules. Reclamation has an irrigation scheduling program (WAT80) on the mainframe computer that has been used by staff for the past several years. It has been our desire to port this program to the UNIX workstation environment with a graphical user interface.

We understand that the Imperial Irrigation District (IID) is in contact with Dr. Luis Garcia and Dr. Terence Podmore, Colorado State University, regarding adapting Dr. Garcia's conjunctive irrigation and drainage design decision support system to the needs of IID. The Denver Office of Reclamation would be willing to cooperate with Colorado State University and IID in this enterprise and offer the knowledge and time for adapting WAT80 to the needs of IID. Tasks involved in our portion of the effort would be:

- Port WAT80 to the UNIX workstation environment

- Embed WAT80 in a spatially oriented graphical user interface

- Adapt WAT80 as necessary for use in the IID area

- Calibrate and field test WAT80

Our staff will work closely with staff at Colorado State University and IID to develop and implement the irrigation schedule component of this effort. We

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Copy to WD for draft response for my signature

CLS

estimate that approximately 5.5 staff months will be required for the irrigation component. We offer these 5.5 months as our portion of the effort.

We have discussed our involvement in this effort with Reclamation staff in the Lower Colorado Region, Boulder City, Nevada. They concur in the value of the coordinated effort between Reclamation, IID, and Colorado State University.

Sincerely,

J. William McDonald

J. William McDonald
Assistant Commissioner
Resources Management

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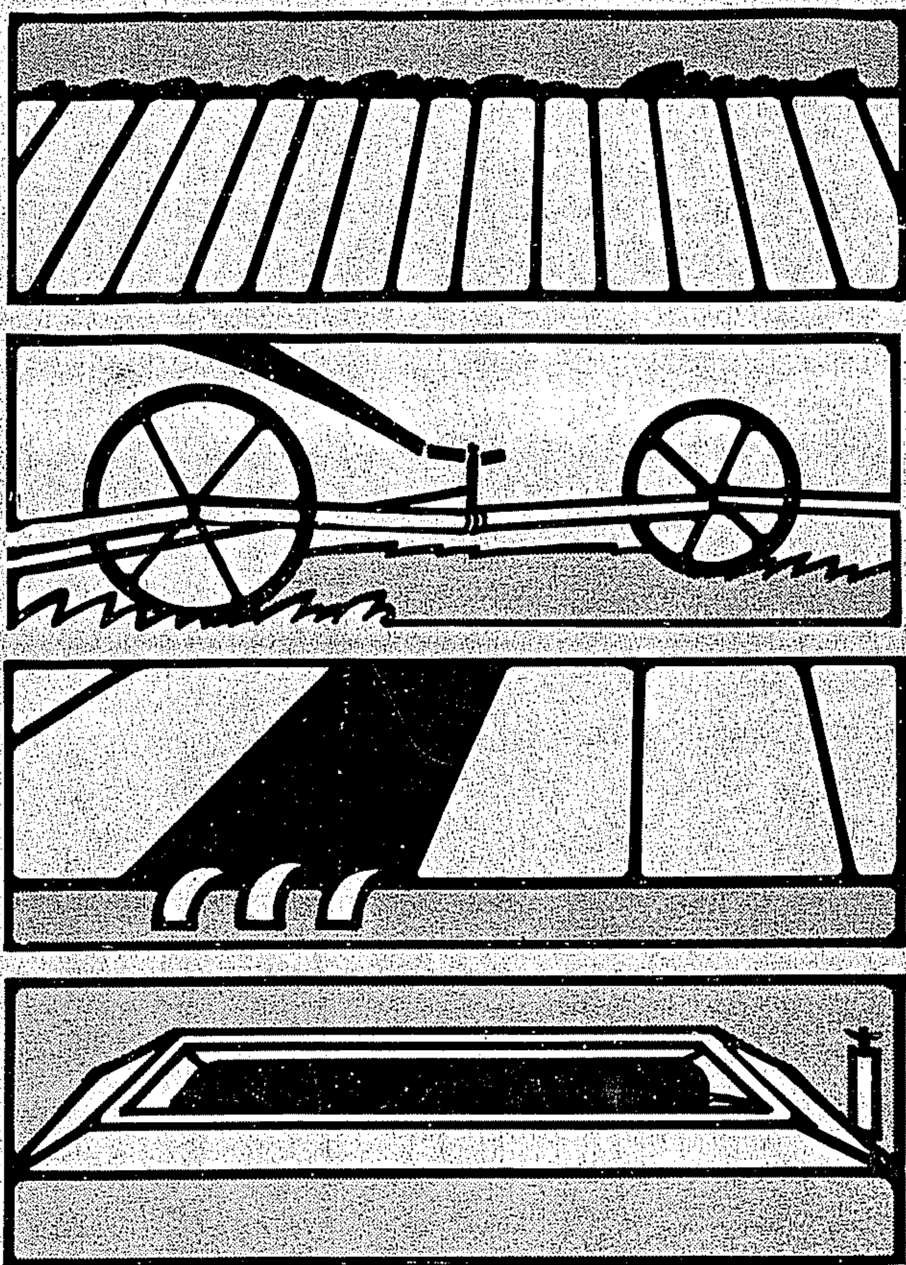

Efficient Irrigation

YOU CAN PLANT MORE LAND WITH LESS WATER

by
John L. Merriam
Professor, Agricultural Engineering Department
California Polytechnic State University

EFFICIENT IRRIGATION

or

YOU CAN PLANT MORE LAND WITH LESS WATER

by
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San Luis Obispo, California

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Table of Contents

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This booklet has been written by Professor John L. Merriam who, for 20 years before starting to teach, was a practicing engineer with the Soil Conservation Service in Southern California and abroad. He is a registered civil and agricultural engineer and a farmer as well. In 1978 he retired following twenty years of teaching practical and theoretical irrigation classes at Cal Poly, a university noted for its practical approach, and now is doing consulting work at home and abroad

Preface

The information in this booklet is pertinent all of the time, but as the sub-title suggests it is extremely pertinent in periods of water deficiency. Water saved then can be equivalent to a major on-farm source of water for all but the best irrigator. It would not be so for projects where too deep and runoff losses are recovered for subsequent reuse.

The irrigator who can increase his efficiency from 50% up to 75% can plant half again as much land as he originally expected to. To illustrate: if the water allocation, as used under a typical current 50% efficient program, would satisfactorily produce a crop on 50 acres, a 75% efficient program will produce a crop on 75 acres.

In a drought year, normal irrigation economics must be thrown out the window -- values have changed. One is no longer greatly concerned with the cost of water, labor, capital investment if irrigation efficiency can be increased. The value now lies in terms of additional production from additional land cropped. There is no other single improvement procedure that can provide so great a return and hence justify so much management or capital input.

If one grows a crop that nets $200 per acre and plants 75 instead of 50 acres, the extra return is $5,000. This will justify borrowing the funds to make the needed capital investment for such improvements as a return flow system, a reservoir, pipelines (permanent or portable), and lining the ditches. Equally important is training the irrigator and paying him a salary commensurate with his enhanced ability not just the

METHOD ADAPTABILITY

Method	Soil Uniformity	Infiltration Rate	Ground Slope	Stream Size	Practical Efficiency	Labor	Power
basin	uniform in each basin	any rate	graded to very level	large relative to basin size	75% to 85%	intensive but infrequent	none
basin-check	uniform in each-basin check	any but very slow	mild	large relative to basin size	80% to 90%	intensive but infrequent	none
border-strip	uniform in each strip	any but extremes	mild	large relative to strip size	70% to 90% *	intensive but infrequent	none or low
furrow	uniform in each field	any but extremes	mild or "contour"	medium	70% to 90% *	intensive but infrequent	none or low
sprinklers	may be intermixed	any but slow	any farmable slope	small but continous	65% to 80%	daily or automate	high
trickle	may be intermixed	all but very extremes	any farmable slope	small nearly continuous	70% to 80%	automate	medium

* A return flow system is necessary to obtain the highest values with border-strips and furrows.

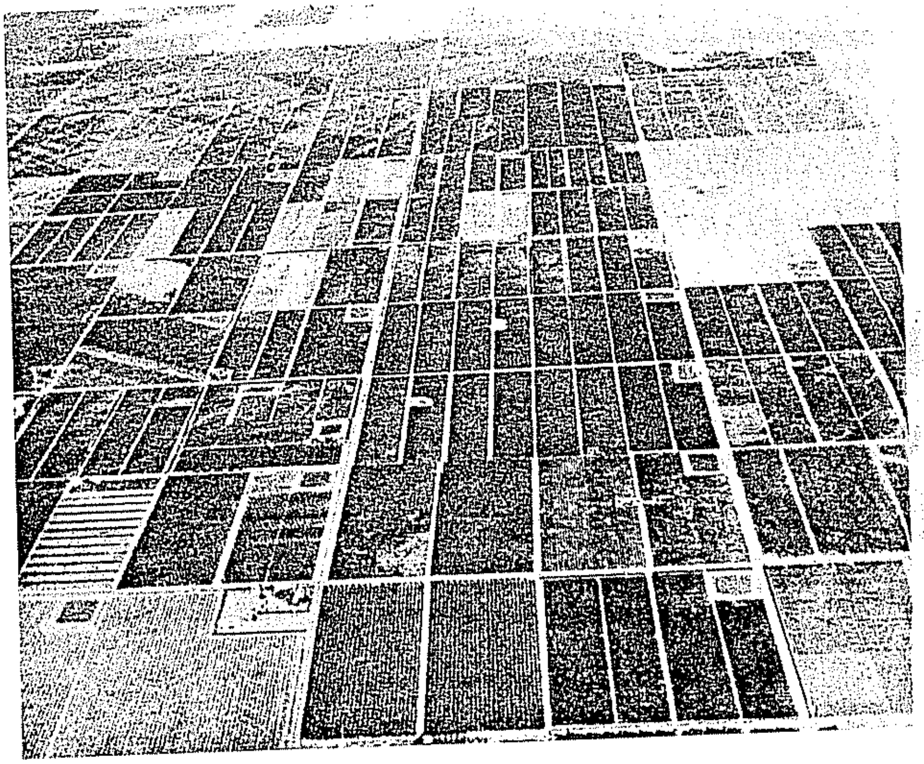
Figure 1

least you can hire a body for, and utilizing professional agricultural engineers, Extension Service people, Soil Conservation Service personnel, or Cal Poly trained irrigation students to make on-farm evaluations of your operation and system to bring them up to the best that is practical. The evaluations may take a couple of days while you are irrigating. Or one may be able to do much of the simpler parts of the evaluation oneself after studying the succeeding chapters.

(A booklet "Irrigation System Evaluation and Improvement," is quite a bit more technical, but would be very helpful for those who will make the effort to study it or who receive help from trained personnel. It is obtainable from Blake Printery, 2222 Beebe Street, San Luis Obispo, CA 93401, for $2.00 tax and postage included.)

The chapters in this booklet first ask the questions to determine whether one can improve his irrigation efficiency (and save labor and power as well as water), and then describe how to do so for the furrow, border-strip, and sprinkle methods. The closing chapter tells about several general practices that facilitate improving effective use of water.

Figure 1, Method Adaptability, on the opposite page, presents general information about where each method can be used and its limitations.



Reservoirs in citrus
Coachella Valley, California

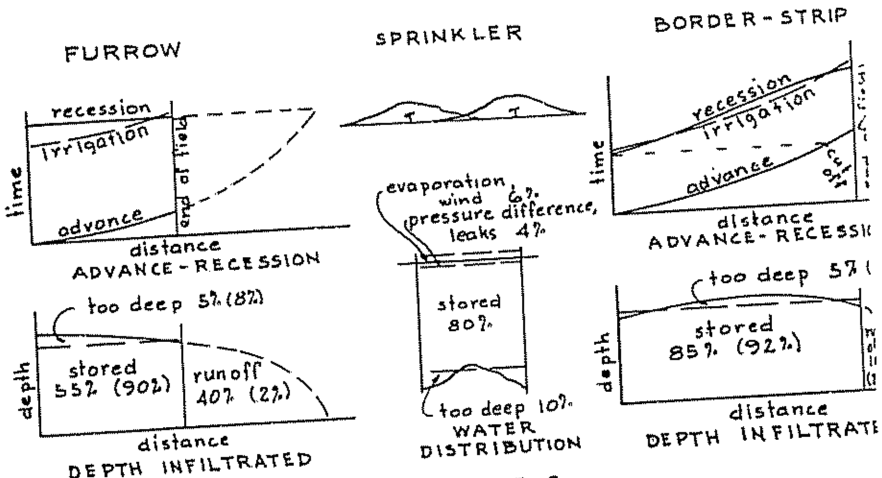
Chapter I

QUESTIONS NEEDING ANSWERS

Where do you fit? Most irrigators are operating at about 50% season-long efficiency (Actual Application Efficiency, AAE). With improved management practices, which in many cases can be easily done, efficiencies can be increased into the 60-70% range. With some capital investment and good management, surface irrigation methods under favorable field conditions, can be increased into the 80-95% range, and sprinklers can be raised up to 75% and possibly 80%. These are Potential Application Efficiency (PAE) values. PAE equals minimum depth stored/average depth applied when everything is just about right. It measures the capability of a system or method and is the only term that may be used to compare them. AAE is defined by the same equation using values found at an actual irrigation. Differences between the two show there is room for improvement usually by management. Low values of PAE indicate need for improving the system.

(The above percent efficiencies, PAE and AAE, are based on the Soil Conservation Service definition of minimum as being the average depth on the lowest quarter of the field, and not the coefficient of uniformity values based essentially on average of lowest one-half.)

Definitions and Terms are described more precisely in the Glossary.



FURROW
SPRINKLER
BORDER-STRIP
recession
irrigation
advance
end of field
time
distance
ADVANCE-RECESSION
too deep 5% (8%)
stored
55% (90%)
runoff
40% (2%)
depth
distance
DEPTH INFILTRATED
evaporation, wind 6%
pressure difference, leaks 4%
stored
80%
too deep 10%
WATER
DISTRIBUTION
recession
irrigation
advance
cut off
time
distance
too deep 5%
stored
85% (92%)
depth
distance

FIGURE 2

The graphs on the opposite page tell the story of what a very good irrigation should be accomplishing. They show where the losses occur and their magnitude when operations are near optimum. For the furrow and border-strip graphs, the advance curve tells the time when the water reached any point down the field and the recession tells when it dried up. The difference between them gives the duration water was at any point infiltrating into the ground. The irrigation curve tells how long water should be at any point. The dotted lines past the end of the field represents water running off.

Below these curves are the depth infiltrated curves. They show the depth of water infiltrated in the time interval plotted above. By proportions of the areas, the distribution of the water can be found and expressed as a percent of the total as shown on the figures. When there is a return flow system (numbers shown in parenthesis), the run-off water can be reused so the only loss is to too deep. The too deep loss is a small amount contrary to what many people believe simply because intake rate decreases with time and very little is infiltrating towards the end of irrigation even though quite a bit of time may elapse.

The sprinkler distribution is independent of the soil intake rate so only a depth infiltrated curve is needed, and there is no decrease in the loss rate with time.

A full evaluation of an irrigation will furnish detailed information and provide the basis for economic decisions. However, the following questions will serve to show the magnitude of the easily obtainable increases in efficiency and the following chapters how to do so.

Fundamental to all irrigation methods are certain essential conditions. "Is it dry enough to irrigate?" and "Is it wet enough to stop?" To properly act in response to these questions requires a water supply that is flexible in frequency, rate, and duration. When the water supplier can't do this, on-farm reservoirs are in order. The photo of a portion of Coachella Valley, which has the highest per acre yield of any USBR project, shows what farmers with expensive land feel is the relative value of productive land versus a reservoir. On properly designed reservoir and distribution system can serve 80 to 160 acres and save much water and labor.

The question "Is it dry enough to irrigate?" - in other words, has the soil moisture deficiency become equal to the Management Allowed Deficiency (MAD), which is the optimum dryness. This question is now being widely answered by the Irrigation Management Service (IMS) program available through many irrigation districts and irrigation consultants. It can also be done by the irrigator making soil moisture deficiency checks using a soil auger. This simple technique will be covered in the last chapter.

The question "Is it wet enough to stop?" can be determin by probing the depth of penetration of the water during irrigation and turning it off at the proper time when the soil moisture deficiency has just been satisfied. Flexibility of Duration is important since all water run after this moment is 100% wasted except for surface irrigation methods utilizing a return flow system.

Now with this background, the irrigator can begin finding his own irrigation efficiency by subtracting from the very hi but attainable Potential Application Efficiency (PAE) values shown on the graphs -- 90% for furrows, 85% for border-strips and 80% for sprinklers -- as follows:

-- If you always run water for 12 or 24 hours or some other fixed number of hours instead of turning it off at a time based on a field check, subtract 10% to 20% or more efficienc points. This is usually the single biggest loss for most systems and especially for sprinklers. (For example, if the system were designed to run 24 hours but 20 hours would have been adequate, one would lose (24-20)/20 = 20%. (Turn it off!) If your crop never shows moisture stress anywhere, you are never under-irrigating so on the average you must be over-irrigating, lose 5%.

-- If you are using surface irrigation and don't have a return flow system, take off 20% to 40% for furrows, or cut back the stream and lose only about half as much. Furrows really need a return flow system to save water and labor. For border-strips don't take off any more as that loss is included in the original figure, but you could save 5% to 15% if you did have a return system or, on sandy soils, carefully pond the water at the lower end. (Invest some capital!)

-- For a sprinkler system designed to run 12 hours, do you make your night run shorter than the hotter, windy day run by an hour or so or alternate the sets to compensate? No, then take off about 3%. Do you have leaking gaskets, old and new nozzles on the same line? Yes, then take off 5%. Have you used a pressure gauge at various locations in the system to see if pressures are reasonably uniform and at the design value -- do you know the design pressure? No, take off at least 5%. Do you open the line valve wide open for all sets? Yes, take off 5%. Do you tip the sprinkler risers along the edge of the field so that instead of wetting the road you put that water in the field for your crop? No, take off 1% or 2%. Do you use the alternate set procedure when you move your line at every other irrigation? No, take off 5% or more. Do you operate in a hot, dry climate? Yes, take off 5 to 10%, and 5% more if it is very windy. Does the sprinkler jet from one set reach or nearly reach the location of the previous lateral location? No, lose 5%.

-- For furrows, do you use a small stream, which takes a long time to reach the lower end (Advance Ratio 1:1) and so over-irrigate the upper end, but gives very little run-off to be saved by a return flow system? Yes, subtract 15 points. [Advance Ratio (AR) = Time of Advance needed to reach the lower end/Time of Irrigation needed to infiltrate desired depth at lower end.] Do you use a large stream to reach the end quickly (Advance Ratio 1:4) and so have very little too deep but do have lots of run-off and no return flow system? Yes, lose 30% to 40% Same as above but do have a return flow? Yes, lose no points. The equivalent to a large stream is a short furrow since the Advance Ratio is the key to limiting excess deep penetration at the upper end.

-- For both surface methods, do you have dissimilar soils and intake rates along a furrow or strip? Yes, lose 5% to 10%. Do you have 24-hour water deliveries and no reservoir? Yes, lose 10%.

-- For border-strip irrigation, do you have water on the upper and lower end of the strip for about the same duration? No, lose 5% to 15%. Do you turn off the water when the stream is more than .6 to .7 of the way down the field for the finer textured soils or more than about .9 for sandy soils so that run-off is excessive? Yes, lose 5% to 15%.

If these questions and answers convince you that efficiencies can be improved then you can save water and labor. And remember that it is not the cost of water and labor that counts in a dry year, but how much more crop can be produced with a limited water supply by planting more area with water conserved because of increased efficiency.

The subsequent chapters describe in detail how to operate to attain the higher values by making one's Actual Application Efficiency (AAE) approach or equal the Potential Application Efficiency (PAE).

Chapter II

MANAGING THE FURROW METHOD

Water is lost in furrow irrigation in two ways -- it runs off and it goes too deep. Stopping or reducing these losses conserves water, and usually labor and energy. In areas where more land is available than water to irrigate it, the value of this water is measured by how much crop it can produce, and the cost of it and the labor and capital to apply it ceases to be of dominant economic importance. Efficient irrigation under such conditions is of great value.

Basic to all irrigation are two questions -- "Is it dry enough to irrigate?" and "Is it wet enough to stop?" The techniques for answering these questions will be covered in Chapter V, but the importance of doing so and the effect on the operation of furrow irrigation systems will be illustrated here.

For furrows, runoff and uniformity of the depth of water infiltrated along the furrow are related to the speed of water reaching the lower end (Time of Advance) relative to how long it needs to be there to do a job of soaking in enough water (Time of Irrigation). This is conveniently expressed as the Advance Ratio (AR) -- the ratio of the Time of Advance (T_{adv}) to the Time of Irrigation (T_i) ideally, otherwise to T_o.

If a large, but non-erosive, stream is turned into the furrow it will reach the lower end quickly if the length is reasonable. The water will be on the upper end only a little longer than at the lower end and a very uniform irrigation will result. This uniformity is measured by the Distribution Uniformity:

$$DU = \frac{\text{average depth infiltrated in lowest quarter of field}}{\text{average depth infiltrated on whole field}}$$

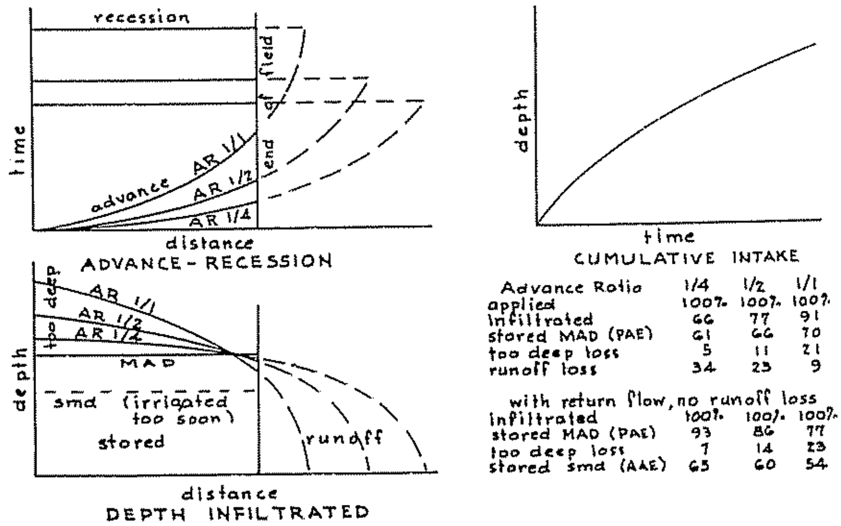
The same effect can be obtained with a smaller stream and a shorter furrow. However, if this relatively large stream continues to run full size for a number of hours more in order to irrigate the lower end, there will obviously be lots of runoff.

There are several management tools to adjust these conditions to get the best results. Changing the Time of Advance by changing the stream size is the easiest thing to do to affect the Advance Ratio and hence the uniformity. The largest usable non-erosive stream will give the best uniformity. Adjusting the length by using gated pipe across the middle of the field, or other ways, may often be practical. Reusing old furrows rather than making new ones each time lets the water move faster, reducing the Time of Advance.

Varying the Time of Irrigation, the other factor in the Advance Ratio, can be done several ways including changing the desired soil moisture deficiency at the time to irrigate (Management Allowed Deficiency, MAD), changing the furrow spacing or its shape, reusing furrows or making new ones, etc. Other things such as driving the tractor wheels or pulling a drag down each furrow may be helpful in reducing the intake rate. Chiseling often is done in a way which results in a different effect in different furrows and it usually increases intake rate. Both of these latter items tend to make irrigation less uniform.

The graphs of Cumulative Intake, Advance and Recession, and Depth Infiltrated shown on Figure 3, are taken from a field evaluation on a compact sandy loam. They are modified only slightly to better illustrate the concepts. They indicate the relative effects of changing stream size to affect the Advance Ratio and the losses going too deep and running off, and the amount that is stored for crop use. Not indicated is the effect on changing length. A shorter furrow with other conditions constant, will result in a smaller AR.

FURROWS



Advance Ratio	1/4	1/2	1/1
applied	100%	100%	100%
infiltrated	66	77	91
stored MAD (PAE)	61	66	70
too deep loss	5	11	21
runoff loss	34	23	9
with return flow, no runoff loss			
infiltrated	100%	100%	100%
stored MAD (PAE)	93	86	77
too deep loss	7	14	23
stored smd (AAE)	65	60	54

FIGURE 3

The Cumulative Intake curve simply indicates at any time the depth of water that would have infiltrated into the soil for the particular furrow shape and spacing that was tested. From such a test, presuming reasonably similar conditions at the next irrigation, a good estimate can be made of how long water would need to be near the lower end (average of the lowest quarter) to satisfy the desired soil moisture deficiency (MAD). Or if one knows how long the water has been at a spot, a reasonable estimate can be made as to what amount of water has infiltrated.

The Advance Curve shows how fast three different size streams would go down the furrow. They have been drawn so that the time it takes them to reach the end (Time of Advance) is 1/4 and 1/2 of and the same as (1/1) the Time of Irrigation.

This represents a range from quite rapid advance to moderately slow corresponding to Advance Ratios of 1/4, 1/2, 1/1. The results of these variations are shown in the table with the curves, Figure 3. It should be studied for trends and magnitudes.

For the irrigations indicated, which were turned off when it was just wet enough to stop, for the AR of 1/4, the percent lost to too deep was 5% of the total water applied, lots of which ran off, for the 1/2 AR, 11% was lost, and for the 1/1, 21% went too deep. Remember there are a number of ways to affect the AR to make it and the too deep loss what you want them to be, and the loss can be kept smaller with furrows than with any other method.

Now, let's look at another too deep type of loss. If it isn't "dry enough to irrigate," but one thinks it is and applies the regular irrigation, lots of water may go too deep. Water cannot be stored in the soil in a greater amount than there is dry soil in the root zone to hold it, i.e., greater than the Soil Moisture Deficiency (SMD), so check it before deciding to irrigate. Graphically, on the Depth Infiltrated curve, all the space above the SMD line now is lost to too deep and the AAE shown in the table is low.

This can be partially alleviated by acting in response to the second question, "Is it wet enough to stop?" If the water were turned off when the depth of water infiltrated at the lower end equalled the SMD rather than at the planned MAD, the loss to too deep from over-irrigation would be eliminated. However, it would start a chain of consequences. The Time of Irrigation would be reduced. This would increase the Advance Ratio. That would result in a larger percent of water infiltrating at the upper end relative to the lower end. However, the effect of all of this could be overcome by using a shorter furrow or a larger initial stream to have the same AR.

To summarize these seemingly involved, inter-related procedures, if you want to put on a lighter irrigation use a shorter furrow, or a large enough stream to get to the lower end with a reasonable AR, and turn it off on time -- the same as one would do for any good irrigation. For annual crops with an expanding root system, an early, light application can easily be done by using gated pipe across the middle of the field effectively shortening the length. The upper and middle lines should be run simultaneously to avoid double irrigation at the middle line. The full length can be used for the heavier, later irrigations. Or the light early applications can be made longer by including part of the "pre-irrigation" depth.

Furrow spacing has a very definite effect on Time of Irrigation. It simply takes longer to move water further out to the side and it goes slower and slower the wider the spacing. Since it is taking longer, it is also going deeper. This all means that if one is putting on light applications one needs furrows closely enough spaced to wet across below the surface during the shorter time. If one is putting on deep irrigations, a wider spacing is allowable. It will then take a great deal longer, perhaps even three times longer, to do the job. This will permit the use of longer furrows at high efficiency. Spacing is also related to soils and can be adjusted to crops and equipment.

Similar management changes can also be accomplished by changing furrow shapes. Vee furrows may be wet 10" wide, a parabolic one may be wet 15", and a broad one which is level across may easily be 24" wide. Since the water moves sideways about the same distance from the edge of all shapes, the area wet, the time of irrigation, and the stream sizes are all correspondingly adjustable.

Looking at the other loss -- runoff -- which may easily be very large, one again finds that it also is related to the Advance Ratio with all of its inter-ties to initial stream size, furrow shape, spacing and length, and MAD and their side effects. The curves and table showing the advance relationships and the Depths Infiltrated indicate that for a rapid advance, AR of 1/4, there is lots of runoff, 34% of all applied water if the water is turned off on time. For the smaller streams, AR of 1/2, it reduces to 23%, and for the quite small streams (which would be similar to a longer furrow and the larger stream) the runoff is small, 9%, but this is also the one that lost 21% too deep.

The runoff loss can be reduced by about one half or more by making one or two cutbacks in the stream size. The first cutback should be made an appreciable time after water is running past the lower end when the loss has become big enough to warrant cutting it back. If it is done sooner as is often suggested, the lower end will be inadequately irrigated and the runnoff at the end of irrigation will be greater. The most economical operation with one cutback is such that the runoff at the time of cutting back is about the same as it will be at the end of irrigation. If the cutback is done in conjunction with the use of a cycling type return flow system, the above cutback operation will minimize the cost and power requirement.

A return flow system should almost always be part of a furrow irrigation system. Ordinarily, it is economically justified as a labor saving device as well as water saving. When the value of water is measured in terms of its productivity, a return flow system back to an irrigation reservoir, is practically the first item to be considered. Using one in conjunction with small Advance Ratios, the Actual Application Efficiency (AAE) values should approach the Potential Application Efficiency (PAE) of about 90% if the soils are uniform and the water is cut off on time.

In order to do this last item, a reservoir may be essential if water deliveries are for units of twenty-four hours.

A gravity reservoir in conjunction with a large capacity semi-automated delivery system is a real labor saver as well as helpful in conserving water since it makes it possible to set all the furrows in a field at one time and to make cutbacks as desired. It also serves as regulating storage for the return flow system.

In summary, furrows on reasonably uniform soils and slopes are the most efficient method of irrigation if proper management uses a small Advance Ratio, turns water off on time, and utilizes a return flow system. Low efficiencies are not the fault of the method, but of management.

Chapter III

MANAGING THE BORDER-STRIP METHOD

Border-strip irrigation has several other common names - border, check, strip check, flood. In addition, it is the most widely used method in California and the least understood. It has a high Potential Application Efficiency (PAE), 80% plus, but is usually operated at about 50% Actual Application Efficiency (AAE). Furthermore, it has the dubious distinction, seldom realized by its users, of being the most sophisticated, complicated, least adjustable method. But when border-strip irrigation is used correctly, AAE can go above 90%, and labor and power requirements are very low.

Because of the complications in obtaining real high efficiency, each border-strip has only one Management Allowed Deficiency (MAD) value, plus or minus a little, that is just right. For this reason, it is best adapted to permanent crops such as pasture, alfalfa, orchards, etc. With good management and planning, it can be made to do very satisfactorily for many deep-rooted annual crops.

This recalcitrant paragon is described as a sloping strip of land fairly level across, which is bounded on the side by borders (dikes, ridges). The soil for the length of the strip should be uniform but one can live - at lower efficiency - with some variation. If the strip is graded to a uniform grade or nearly so, lengthwise and across, it is called a graded border-strip.

Where soils are too shallow and somewhat undulating and much grading is not practical, guided border-strips are feasible. For these, the grade along the strip is allowed to vary to conform somewhat to topography, and the strips are made narrower so they are easily made level across. They often run nearly straight down hill. (The true objective of land grading is not to create a plane surface, but is to improve irrigation.)

To understand the limitations and management of border-strips, one can best start from the optimum conditions as shown in the adjacent graph, Figure 4. The Cumulative Depth Infiltrated curve indicates the depth of water infiltrated from a ponded condition after any length of time as found from a field evaluation test. It can be approximated from studies on typical soil textures.

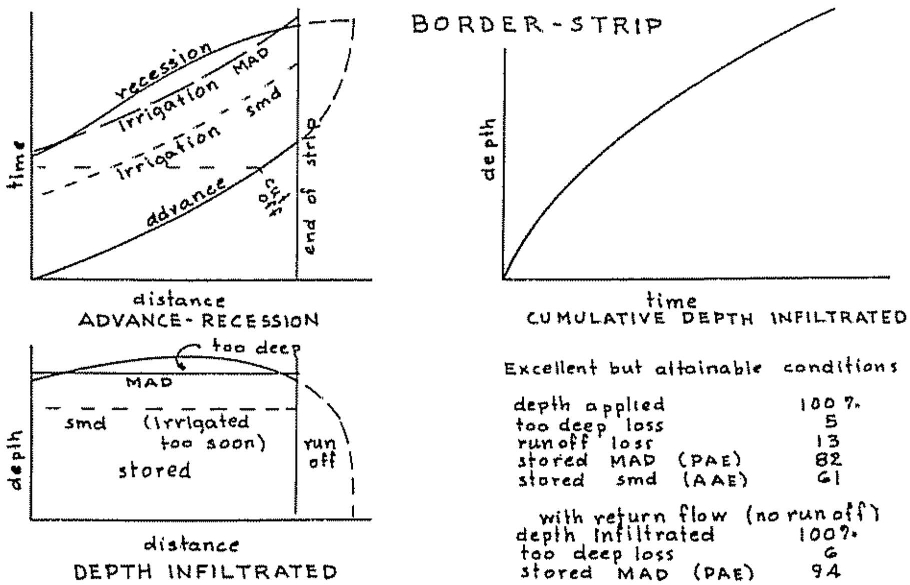


Figure 4

The Advance and Recession curves are respectively plots of the time it took the water to move (advance) down the field to various points usually each 100 feet apart, and the time when water disappeared (receded) from the various places. The duration of time water was at any location with an opportunity (To) to infiltrate there is the increment of time between the two curves.

By using this time of opportunity in conjunction with the Cumulative Depth Infiltrated curve, the depth corresponding to the increment of time at each location along the strip can be found. The plotting of this depth and distance is the Depth Infiltrated curve from which by proportion, the losses and stored percent and depths can be determined.

The detailed procedure for obtaining all of this information requires making a field evaluation. That process, which is moderately involved, is described in the booklet "Irrigation System Evaluation and Improvement," mentioned in the Preface.

However, the simple procedure of timing how long it takes water starting at the upper end to reach the middle and lower end of the strip, where it was and when it was cut off, and when water is no longer on the surface at the top, middle, and bottom (with or without ponding) is just a matter of observation. From this information, the Advance and Recession Curves can be sketched. If distance units of 100' are used, better curves can be developed.

The graphs shown represent a real good job of irrigating - better than can be done every time. However, measured tests have given values better than this. Poorer, but easily improved conditions, are described later.

The ideal condition for uniformity exists when the Advance Curve has been made "parallel" to the Recession Curve. For this condition, about the same time of opportunity occurs at each end with some extra in the central portion. The times are made about the same by simply turning in the stream size that moves at the desired speed. The slope of the Advance Curve is adjustable with stream size, but the slope of the Recession Curve is fixed. This is true because the water that is just disappearing at any point by infiltrating or moving on, is always doing so under the same physical condition for each specific strip. Since the Recession Curve is fixed in shape, it becomes the control item for border-strip irrigation. This is a distinguishing and unique condition. The time at which the recession starts is controlled by when the water is turned off plus a little more (Lag Time) taken by the several inches of water ponded at the top to drain off and infiltrate.

The depths infiltrated will vary appreciably less than the time difference between the Advance and Recession because any extra time is at the end of irrigation when the infiltration rate is the slowest. This is illustrated by the Cumulative Depth Infiltrated Curve. Very uniform infiltration along the strip is possible. The table shows for this illustration that only 5% went too deep because of the non-uniformity. Up to 10% is a reasonable loss.

Runoff loss is largely controlled by how far back from the lower end the water is when it is turned off. Where it should be is related in a complicated way to ground slope, stream size, flow rate, strip length, Soil Moisture Deficiency (SMD), soil conditions, crop conditions, soil and water temperatures, etc. The practical answer is by trial and error knowing the objective which is to turn the water off late enough to have the 3" to 6" depth of ponded water in the upper part of the strip flow on down to the end and adequately irrigate there, but not so late that too much flows on by the end and runs off. On fine textured soils with low gradients and long strips this may occur about .6 the way down the strip. For medium textures, it is often .7 to .8 down the way, and on high intake rate soils it will be near the end.

Irrigation is an art and a science. This part is art. With adequate art, the runoff loss is about 10% to 15%. A return flow system eliminates most of the art needed as well as the runoff loss.

In summary of losses, the too deep loss is low and uniformity is high if the Advance Curve is made about "parallel" to the recession by simply using the right size stream, and the runoff loss is small if the water is cut off at the correct distance.

Now comes the intransigent part imposed by this excellent method. Up to here nothing has been written about the two basic questions, "Is it dry enough to irrigate?" and "Is it wet enough to stop?" They must be answered.

The irrigation curve (MAD) drawn in conjunction with the Advance and Recession Curves is drawn parallel to the Advance Curve and above it by the time it takes to infiltrate the desired irrigation (MAD). It represents a specific time related to a specific depth of water as taken from the Cumulative Depth Infiltrated Curve, and only at the ends is it just barely below the recession in order to have the minimum depth infiltrated show up as the average of the lowest quarter of the field. If a different depth, and related time, were desired, a different line would be drawn which would be above or below the Recession Curve and so would therefore represent under or over irrigation. There is no way that the excellent condition first presented can be maintained except for the original MAD. However, reasonable compromises with near perfection can be very good.

With the border-strip method only four things are adjustable, and the last of them is often not practical. They are the stream size affecting the advance rate and uniformity, the MAD affecting the duration water should be on, the distance and time at cutoff, and the length of the strip. Compromises, but at reasonable efficiencies, are essential.

Illustrations of less than the best will be helpful in identifying problems and what may often be done to correct them. Since the scope of this booklet is limited, appreciable study may be needed to fully appreciate the complexities. (Additional illustrative curves are included in the Appendix.)

The first illustration is shown in Figure 4 and the table. If the question "Is it dry enough to irrigate?" is improperly answered and full irrigation is applied four days too soon as represented by the SMD line, the Actual Application Efficiency (AAE) drops from 82% to 61%. If this were standard procedure, (.82-.61)/.61 = 35% more land could be planted with the water saved by irrigating four days later when the soil is dried to the MAD.

If one is among the unfortunate irrigators who must take their water too soon, because of rigid schedules, then the following compromises must be made: the date of irrigation being fixed, one will irrigate at the small SMD existing at that date and try to be reasonably efficient in applying that depth of water. Since the reduced depth takes less time of irrigation, the stream should be near the lower end faster than before. This will require a larger stream. The Recession Curve, that inexorable control item, does not change its shape so water is at the lower end longer than at the upper end and more runoff may occur. This condition is represented by the curve titled Stream Too Large in Figure 5. The graph shows that it is quite possible to over-irrigate the lower end of a strip, or under-irrigate the upper part. The identifying feature for too large a stream is the divergence of the Advance Curve from the Recession rather than being "parallel."

The graph, as drawn, corresponds to about 20% water lost to too deep and 15% to 20% running off for a 60% to 65% efficiency. This is not too bad. With a return flow system it is a respectable 80% even though the stream was too large.

The next graph representing too small a stream - a very common problem - is diagnosed by having the Advance Curve converge toward the fixed Recession Curve. If one has a fixed stream of water as from a well, the strip can be made narrower to increase the effective stream size. With the moderately smaller stream condition shown, very little runoff occurs, -5%,

GRAPHS OF UNDESIRABLE CONDITIONS

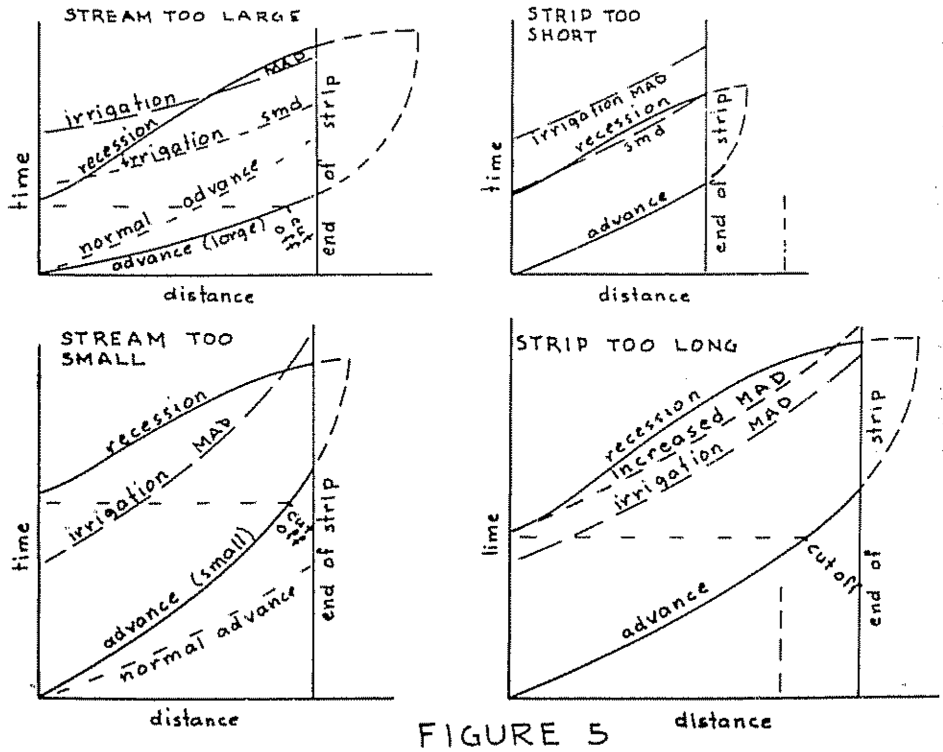


FIGURE 5

and the too deep loss is about 20%. AAE would be a respectable 75%. This may be a fairly good compromise if a return flow system is not utilized. If much too small a stream is used, results will be very poor.

When the strip is too short, as shown by the graph, only a much smaller SMD can be used or losses are excessive. This is to be emphasized - border-strips are NOT adaptable to short fields, and very seldom is efficiency improved by just shortening the length. This latter advice is often given, but it is incorrect. It does apply to furrows, but not to border-strips unless other factors such as MAD are drastically changed.

Basins may be used to replace short border-strips.

The last of the graphs on Figure 5, shows conditions when the strip is too long. As before, the stream size is the desired one to keep Advance and Recession Curves parallel. The graph indicates that a larger MAD is needed because the stream must be run longer to go the greater length and be turned off later. A larger stream would also be a compromise technique with this longer strip. Very long strips are feasible if large MAD values are used.

For annual crops with an expanding root system, the early irrigations are usually light with deeper ones later. With border-strips, the light ones would not be efficient. Two management alternates are practical. The early irrigations can be made larger than needed with the excess being used in lieu of a pre-irrigation. Or portable pipe can be used to cut the length in half for the first part of the season and then removed to use the full length for the larger, later irrigations.

The question "Is it wet enough to stop?" is a hard one to answer. Hopefully, the desired depth to just replace the SMD would occur simultaneously near the upper and lower ends. However, it could be either one. Unfortunately, when this condition occurs, the water may not be far enough down the strip so it will have to run longer to irrigate the lower end. Or it may be too far down the strip, and be running off a lot. Again compromise is inevitable.

In addition to the problems illustrated, there are obviously many more combinations of the controllable items: stream size, MAD, time and distance to cut-off and length, to which should be added return flow systems.

The diagnosis of conditions is obviously rather complicated. Some assistance can be obtained from trained people. Cal Poly State University, San Luis Obispo, agricultural engineering students and graduates, and some others have studied evaluations and they can be helpful. Several engineering and farm management firms have adequate staff. The Soil Conservation Service and Farm Advisors' Offices have some experienced personnel. For the tremendous job of efficiently using a short water supply, most irrigators will have to depend on themselves. Hopefully this booklet will be of assistance.

The value of water is not its cost, nor the labor to apply it. It is measured by what the water and labor will produce when water is in short supply.

Chapter IV

MANAGING THE SPRINKLE METHOD

Sprinkle (and trickle) irrigation method is unique in contrast to surface methods in that it is independent of soil uniformity and topography in its adaptability. It is also compatible to a small steady stream of water when surface irrigation works best with large flows. However, disregarding adaptability and contrary to popular opinion, sprinkle has the lowest potential efficiency of any normal irrigation method. Also, it is difficult to modify for drought conditions.

The basic reason for the good reputation it does have is that most systems are fairly well designed and the design efficiency is presumed to be the operating efficiency. However, in general, the pre-nozzle losses are ignored and the coefficient of uniformity is frequently incorrectly thought of as being the efficiency of the method.

This chapter will present the management procedures to identify and alleviate its losses in order to increase efficiency up to the fairly good values that are attainable. A number of factors will be presented that apply to sprinklers in general, and then the unique conditions will be covered for the following specific variants of the method: single line (hand move, side roll, end tow), multi-line system (permanent, solid set, side roll with trailing laterals), and orchard (over-tree, under-tree, permanent, portable).

Some of the techniques may be fairly expensive or labor intensive, but in a water deficient period the value of water is in its productivity. If an efficiency of 60% can be raised shown on the figure, serious loss of water to too deep will occur since everything below the SMD line now goes too deep. For example, if a 20-hour set would replace the SMD, but the run is 24-hours (24-20/20) = 20% water is lost in addition to the regular losses.

It is essential that the operating frequency or duration be made to conform to that needed to replace the SMD existing at the day of irrigation. This will often require an inconvenient duration of operation, but water run too long is 100% wasted. There is no return flow to save water with sprinklers. Not properly answering the second question is the principle reason the sprinkle Actual Application Efficiency (AAE) seldom equals the Potential Application Efficiency (PAE).

Another loss that puts water too deep is caused by the non-uniformity of the sprinkler application pattern. Most individual sprinklers at their best operating pressure, put out much water close to the sprinkler and taper out to zero at the edge. This results in a somewhat conical shaped pattern. By overlapping one sprinkler well past the next along the line, a long triangular tent-like pattern results. This is then moved sideways to nearly reach the next line to overlap the tent-like patterns.

With the right combination of nozzle size, pressure, sprinkler spacing along the lateral, and distance between laterals, a reasonably uniform overall pattern results from the many individual conical patterns. However since nozzle size and pressure are often compromised in the design to apply the desired depth in a 12- or 24-hour duration, the best pattern is seldom attained. Modifications to help will be discussed later.

A field evaluation (in which catch cans are set out and depth measured as described in the booklet, Irrigation System Evaluation and Improvement) is essential to determine the distribution uniformity coefficient (DU). (DU = average depth infiltrated in the quarter of the area receiving the lowest depth/average depth infiltrated). The value of DU for good operations will range from 75% to 85%. This indicates the too deep loss is from 15% to 25% of that infiltrated when the flow is shut off on time. (Those values correspond to the commonly used coefficient of uniformity values of about 83% to 90%.)

The pattern is also distorted by wind. This is alleviated by using a lower pressure to create fewer small drops which are more affected by wind. Laterals should not be placed parallel to the wind, 45° to 90° being less distorted. Avoidance of windy periods is the best control, and 24-hour sets are better than 12-hour ones. Where practical, the use of alternate sets described later is very helpful as is also closer spacings along and between the lateral. The decrease in DU varies from 2 or 3% to perhaps 6% for fairly high winds.

Other too deep losses (which are not included in the PAE evaluation figures which are measured at the sprinkler nozzle) also occur. These losses need to be included in the field efficiency as water to satisfy them must be delivered to the field. These losses are leakage from poor gaskets, losses occuring while filling the lines and before pressure seals the gaskets, and the water lost while draining the laterals. They amount to from 2% to 7%. Good maintenance can reduce the higher values.

Another loss of a similar nature is that caused by having different pressure along the lateral caused by friction and differences in elevation, although the latter can also be helpful if downhill. The usual design limit of a 20% reduction in pressure along a lateral results in 10% more water flowing from the first sprinklers than from the last. If the flow from the sprinklers at the lower end is what is desired, about 3% excess water will be applied along the upper part of the lateral.

This can be alleviated by using flow regulating devices in the risers or a larger diameter lateral with less than 20% friction loss. The latter will reduce pumping costs.

However there is a complication due to the 20% pressure change in that there is an effect on the pattern. The DU at the various places along the lateral will be different. One cannot offhand tell whether the lower flow and pressure at the lower end might not also coincide with a less desirable DU. Field evaluations are definitely in order.

To summarize the too deep losses: the system may be run for an incorrect duration which is correctable, the pattern DU may be poor and corrections will be discussed under each type, line losses occur which may be reducible with good maintenance, and flow and pressure variations along laterals may be helped by installing flow regulating devices or having less pressure loss or more consideration for ground slope.

The in-air losses are unique to the sprinkler method. They are included in the PAE and AAE values since they occur after the water leaves the nozzle. The evaporation loss is related to the relative humidity and will be affected some by temperature, wind, and sprinkler layout, by water temperatures, and somewhat by drop size. The latter is a function of pressure and nozzle diameter.

This loss varies from about 5% to 15% and even higher under severe conditions. The in-air evaporation is less at night when it is cooler and the relative humidity is higher. However during the daytime water on the plant leaves effectively stops plant transpiration so that water normally removed from the soil remains there. The net effect is that there is usually only a small difference whether water is applied during the day or night unless severe climate conditions prevail. If they do, sprinklers may become impractical particularly with saline water. A 20% evaporation increases water salinity by 25%.

Where multi-line systems (solid set, etc.) are used, evaporation will be reduced except for the up-wind lines.

Wind drift losses are only a few percent for normal pressures and moderate winds though the pattern will be affected. For extreme conditions of high pressure with fine drops and appreciable wind, it may be as high as 5%. Multi-line operation may recover part of the drift. Lower pressure and avoidance of very windy periods are obvious ways to reduce the loss. They may have side consequences -- less water, larger drops, longer duration -- that makes these changes impractical, so management compromises.

Another general problem with sprinklers occurs along the edges of the fields. Since there is no lateral line set beyond the edge, only one line of sprinklers lacking the usual overlap applies water there. In order to get a fair amount of water - but usually a deficient amount - the lateral in a typical operation is set fairly close to the edge and water is thrown outside the field. This can be overcome in some systems by tipping the risers so that the water hits the ground at about half the move distance or less from the lateral. This will concentrate the over-thrown water in close and make the application quite uniform. The impact of the jet may damage some crops and will certainly pack bare soil. The end sprinklers or the laterals may have their risers permanently bent a little.

If, by utilizing some of the various ways to improve efficiency, the value of the PAE of the system is improved, the duration of operation must be correspondingly reduced. This probably will be to some inconvenient duration in order to infiltrate the same minimum depth as before, or a larger MAD must be used. If this is not done, AAE will not increase and more water than before will be lost to too deep.

When water supplies are decreased from regular sources or because of falling water tables in wells, all of the available land may not be planted even with increased efficiency. If laterals are shortened so that unplanted land is left at the far edge of the field, the flow in the lateral will be correspondingly reduced. Less pressure will be needed to overcome friction without affecting the sprinkler pressure, so power may be saved. If a 1320 foot lateral were reduced to 990 feet, the pressure could be reduced from say 65 psi to 56 psi for about 15% reduction in power. It would also provide more uniform sprinkler flows along the lateral and save a little water. To save power, the pump impeller would need to be changed which is a fairly inexpensive job. Throttling the inlet valve will not save much power.

If throttling is currently being done, a review of the pump is in order to see if changes can be made. For constant speed pump, a 10% reduction in impeller diameter results in a 10% decrease in flow, reduces pressure 20%, and horse power by 30%.

For the single line sprinklers - hand move, side roll, end tow - the total area and the set area may be decreased by reducing the lateral move distance. This usually increases the DU and application rate which will reduce the time of irrigation or result in more water being applied at the low quarter area. It therefore may be practical to reduce the flow rate and pressure saving water and energy. Renozzling may sometimes be desirable. The new condition would require a field evaluation to determine the new DU.

Another practice that should be standard with the single line system because it almost invariably improves DU by 5 to 15%, is the use of "alternate sets." In this practice the regular move distance and frequency are used each time, but at alternate irrigations the starting location for the lateral is midway between the previous sets. The high application area of the first set tends to compensate for the low application of the alternate sets. A minor edge problem occurs due to the need to compromise the distance in from the edge of the field at the start. And again duration or other changes must be made because of increases in efficiency. A wider than normal move distance often becomes very acceptable with alternate set utilization. The improved efficiencies again require a reconsideration of the duration of the set.

The multi-line systems -- permanent, solid set, side roll with trailing laterals -- are less amenable to modification. Changes of spacings are not feasible for permanent laterals and solid set, so the alternate set techniques cannot be used. Closer spacings usually resulting in higher uniformity may be easily done with solid sets when first laid out. Risers along the edges may be tilted for some crops.

Modifications that may be practical include changing pressure and related flow rate and probably DU, varying pressure at alternate runs, and operating for the correct duration and then shutting down or starting the next block is essential.

Evaluations are important for solid sets and permanent lines since, for economics which is good design except in drought, pressure variations may be rather large. Smaller nozzles to reduce flows to obtain more uniform pressures and possibly a lower one, may be helpful. This will change duration but on automated systems this poses no great problem. It may also be necessary to add or subtract one line in the block to balance flows with the pump, and also the frequency of coverage. Remember, less water and time is needed with better efficiencies.

Orchards and vineyards have several variations of sprinklers. A common one is permanent over-tree. These lack adjustability and their pattern cannot be evaluated. It is often poor at the ground level due to plant interferences. Use of a probe to check depth of penetration in many areas may be helpful. If over-irrigation is not very great, the extensive root system will absorb water wherever it is, but there will be dry areas develop during the middle or latter part of the season. About the only management tool is to avoid over-irrigation and possibly operate at different pressures at different irrigations to vary the pattern.

The open field type sprinklers requiring overlap for uniformity have been used as permanent or portable under-tree sprinklers. They are sometimes facetiously known as "through-the-tree" sprinklers. If there is much tree interference, and there usually is, resulting in excessively wet and dry areas, the uniformity can be quite poor often resulting in ponding and runoff. If they are portable, the alternate set technique may be helpful.

The under-tree sprinkler, properly known as an "orchard" head, should cover the area between four trees with a uniform depth pattern not dependent on overlap from adjacent sprinklers. They usually operate at fairly low pressure. Such a setup can be permanent or portable. Several water saving and management practices are helpful in drought years to maintain production with a reduced water supply.

Most of these heads are adjustable, and while adjusting them may be a formidable job, improved quality and yield have great value. They should be adjusted to produce as uniform a pattern as practical, especially avoiding areas of excessive precipitation which could be lost to too deep. The duration of flow should be such that all but perhaps the last one or two irrigations should penetrate nearly to the bottom of the root zone. Some may be shallower to save storage for rainfall.

In order that about this depth, never more and possibly a little less, is attained, the area wetted may need reducing by adjusting the range and/or pressure. To summarize - wet only as much area as water is available to penetrate the root zone. Do not put on shallow, large area irrigations, but do force the tree to ration itself by using large MAD values and the deep roots. Efficiency above 85% is attainable.

To summarize sprinklers: they are widely adaptable to intermixed soils and unlevel topography. They have more built-in losses, before and after the nozzle, than other methods. They are easily misused, particularly by running too long for an existing SMD. They have limited capability for improvement as a system because they generally are fairly well designed. Management changes in some cases need to be based on a field evaluation. Such changes to improve uniformity may include: varying the spacing and move distance of the sprinkler and using the alternate set technique; varying pressure, flow rate, and nozzle sizes; and tilting risers along the edges of fields. Additional important techniques include varying the MAD and corresponding duration of flow, and, above all, turning off the flow when the SMD has just been satisfied, or shortly before for drought operation.

Under-tree orchard heads can be adjusted to improve uniformity, and to balance the area wetted with a reduced water supply to permit penetration to nearly the full depth of the root zone with negligible too deep loss.

Several procedures may involve a change in the pump. The latter may be as simple as using a smaller impeller.

Chapter V

MISCELLANEOUS MANAGEMENT METHODS

The preceding chapters have presented the value and need for efficient irrigation, particularly during the water deficient periods, and also how to operate furrow, border-strip, and sprinkler systems to attain high efficiency. Certain management techniques in addition to operations need further development beyond that previously presented. They will be covered under the three often mentioned phrases: "Is it dry enough to irrigate?" "Is it wet enough to stop?" and "Losses," and the common closing heading of "Miscellaneous."

"Is it dry enough?" requires two "yardsticks" -- Management Allowed Deficiency (MAD) and Soil Moisture Deficiency (SMD). MAD is first expressed as the percent of the available moisture in the root zone that can desirably be used and correlates with the stress that will occur in the crop in the specific soil and climate condition. This percent is often taken as 50%, but desirably should often be 40% to 80% depending on conditions.

When one has selected the MAD percent and knows the available moisture relations for his soil and depth of root zone, he can multiply them and determine what inches of soil moisture can desirably be removed from the soil (MAD inches) at the time to irrigate. The irrigator should replace the deficient inches depth comparable to the same inches of rain.

For example, a 60% MAD may be the desirable value to moderately stress a crop in a medium textured soil. If the root zone is 5 0' and the available water in the soil between field capacity and wilting point is 1.8" per foot, the value of MAD = 60% (5.0' x 1.8"/') = 5.4". In other words that is how dry management says it should be at the time of irrigation so a rainfall of 5.4" should be prayed for, or that much plus the losses should be obtained from a more likely source.

The second "yardstick" is how dry is it in the root zone. What actually is the Soil Moisture Deficiency? Does it equal the MAD? This is determined many ways. A common one is by intuition which occasionally may be close but most often is used with too much "worry factor" and results in much wastage of water.

Observation of crops for signs of incipient stress, slight wilting, color change, slower growth, etc., can be quite practical in selecting a date for irrigation. However, it does not indicate what the SMD is so does not furnish knowledge of how much water is needed.

Other techniques that indirectly tell that it is time to irrigate include the use of tensiometers, electrical resistance blocks, evaporation pans, calculated evap-transpiration, neutron probe, etc. These must be calibrated with field conditions to estimate the SMD and when and how much water should be replaced.

A simple, less expensive, more direct, more informative, and -- with some personal experience -- as precise a method is the observing of the actual soil moisture deficiency in the field. The chart (Figure 7 in the Appendix) describes the feel and appearance of the various textures when they are deficient the indicated amounts per foot of soil profile. The irrigator should replace the observed deficiency. It should be the same as the MAD at the date of irrigation. In any event, don't put on more, and not less, unless a limited irrigation is desired.

The following is an illustration of the use of the chart. A soil auger* or sample tube is used to obtain samples of each foot of profile. If the top foot condition matches the description of the soil (texture, feel, appearance) indicating a loam soil, 1.8"/' deficient (wilting point), second foot 1.0"/' deficient, third foot .4"/' deficient, and fourth foot 0.0"/' (field capacity), the soil is deficient the sum of these, 3.2", and the root zone depth is about three feet. The irrigator should apply 3.2" of water plus that needed to satisfy the losses. He should check the soil at several locations. Don't complain about the work, because you can hire irrigation management service (IMS) companies to do it, but it is essential that the question be answered.

Another simple guide can be used to tell about when to make a check. It can even be refined to schedule when to irrigate, but it must be confirmed every couple of irrigations by a soil moisture deficiency check. This is a gallon can nearly full of water set out in the sun. Before the MAD depth has evaporated, make a field check. By varying the initial depth of water in the can, the evaporation rate can be varied to approximate the evapo-transpiration rate of different crops.

The selection of the MAD value involves many factors. (A copy of the American Society of Agricultural Engineers technical paper describing this may be obtained from the Agricultural Engineering Dept., California Polytechnic State University, San Luis Obispo, CA 93407.) A value of 50% correlates with the top part of the root zone being dry (wilting point) and of course the bottom being wet (field capacity). For the most efficient production of crops per unit of water, the crop should be stressed and values of 60% to 80% may be

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* An excellent soil auger can be obtained from Art's Machine Shop, Harrison St. at Oregon Trail, American Falls, ID 83211

economical. The following tables indicate the MAD, water use, and yield relations from tests made at Prosser, Washington, for corn and sugar beets. There is also a significant saving in labor with the larger MAD values.

CORN

MAD %	No. of Irri.	Yield bu./ac.	Water used	Yield bu./in
40 (wet)	9	128	33.2"	3.9
65	4	118	25.3"	4.7
85 (dry)	3	110	23.6"	4.9

SUGAR BEETS

MAD %	No. of Irri.	Yield ton/ac.	Water used	Yield ton/in
40 (wet)	12	37	46.2"	0.80
65	8	36	37.3"	0.98
85 (dry)	6	34	32.0"	1.05

These tables indicate more land can be planted with a limited water supply and a larger total production obtained though at a lower rate per acre, if a larger MAD is used.

The second question "Is it wet enough to stop?" can be answered in several ways. The most simple is to use a steel rod 3/8" or 5/16" in diameter about 4.0' long with a tee handle. The end of the probe is left square across. It is not pointed since it is used while irrigating to feel the change in resistance to being pushed through the ground between the nearly saturated soil being wetted and the drier soil below. When used in sticky soils, the lower tip should be slightly enlarged so the soil won't stick to the side. This permits the tip to be more sensitive to changes in resistance.

The probe is used during irrigation. It can be used to quickly make many tests in many areas of the field. Since the water will continue to move downward in the soil for a couple of days after irrigation, the depth of water and probe penetration should be about half way down into the root zone when the water is turned off.

To develop confidence in its use, a soil moisture check should be made with an auger a couple of days later to see just where water did penetrate. If not enough was applied, a slightly drier (but still quite wet) condition should show up at the bottom. If too much was applied, it will be wet all the way indicating some unknown excess was applied. When water is deficient or expensive, under-irrigation is economical.

A second way to stop irrigation is to run out of water. In other words, order or pump an amount that equals the SMD plus losses, and no more. This amount (depth on the field plus losses) can be calculated. It is equal to the flow rate (cubic feet per second, cfs; gallons per minute, gpm; miner inches, M.I.) multiplied by the time water was running onto the field. Either of two equations is commonly used. The first is:

cfs x T hours = acres x inches depth which is conveniently expressed and easily remembered as 1.0 cfs x 1.0 hour = 1.0 ac x 1.0 inch deep.

For example, how long should a stream of 5.0 cfs be run on an 8.0 ac field to satisfy a 3.5" SMD at 70% efficiency? To allow for losses, one needs to apply 3.5" ÷ 70% = 5.0", then 5.0 cfs x T hours = 8.0 ac x 5.0". The duration of flow is 8.0 hours. Of course this time must permit just the desired depth to infiltrate. Usually the duration, depth, and flow rate are known and the question is how many acres can be irrigated.

Gallons per minute can be converted to cubic feet per second by this ratio: 450 gpm = 1.0 cfs. Also, 50 Southern California miner inches = 1.0 cfs, and 40 Northern California miner inches = 1.0 cfs.

The second convenient formula is: Depth (inches) = Time (hours) x 96.3 x gpm/area (square feet).

Losses can be alleviated by several management practices in addition to the too deep and runoff losses written about in the preceding chapters.

Transpiration Irrigation Ratio (TIR) (the percent of the water applied that is transpired by the crop) can be improved by reducing the losses to evaporation. The direct losses from the water while it is being applied are not reducible in a practical way for any of the methods.

However, the evaporation from the ground surface after irrigation -- which may amount to .3" to .8" each irrigation -- can be limited in several ways: shading the wet ground by growing a crop or mulching; reducing the area wetted by irrigation by use of furrows, or orchard sprinkler heads wetting only part of the area; reducing the frequency of irrigation by using a larger MAD; not cultivating unless weeds are being competitive with the crop; etc.

Alternate side irrigation of row crops or orchards should almost always be a standard procedure because of several advantages. The practice consists of first irrigating one side of the plant (every other row) which will require only half of the normal stream and permit a smaller capacity supply system. Then at half of the normal irrigation frequency, irrigating the other side.

For many fields this will require very little more work and usually no more total labor time. The advantage to the crop results from one side of the crop always being fairly wet. This may permit larger MAD values which allow longer runs, more efficient irrigation, longer intervals between irrigation, and so less labor. It also provides a dry area in the field for easy access.

Return flow systems, which recover run off water from surface irrigation systems and should almost always be utilized, have three general ways to function. The runoff water can be accumulated in a fairly large (several acre feet) reservoir (sump) at the bottom and pumped out using a fairly large pump and pipeline for direct inflexible use on a field at a convenient time.

Or a smaller sump, and a fairly large pump and pipeline can be used. Pumping is started after runoff has practically filled the sump, pumping both runoff and stored water. This generally involves more irrigation labor to distribute the water and may not be convenient in time.

The third consists of a small cycling pump, sump, and pipeline returning runoff as it occurs to a gravity irrigation storage reservoir from where it can be re-regulated for convenient use. This is the most desirable and generally the most economical.

For efficient use of water and labor, the on-farm distribution system should be semi-automated, be easy to use, and have a large enough capacity to keep the irrigator busy. It would ideally consist of a supply flexible in frequency, rate, and duration such as can be obtained from an overnight gravity storage reservoir. The delivery system from it must be capable of a delivery that is flexible in rate and duration, be of large capacity, and permit finger tip control at the point of application in the field.

This can be obtained from a reservoir by using a closed, or a semi-closed pipeline with a Harris float valve, or a level top ditch maintained full regardless of the rate of flow by an automatic control such as a Neyrpic constant downstream level control gate. Distribution from it for furrows can best be done utilizing small gated pipe reaching a short distance (100' to 150') each way from controlled outlets.

With such a layout with the control valve wide open, all regulation is at the individual gated pipe outlet to the furrow. However, after the individual outlets are set in a unit of gated pipe, the starting, cutting back, and turning off is done at the individual controlled outlet from the supply system.

For border-strips, the controlled outlets can place water directly into the strips at any rate and number up to the capacity of the system which should be large.

This type of a system is considered as semi-automated because it is manually operated at the point of distribution, but variations in rate from the reservoir require no work on the part of the irrigator since the closed pipeline or float valves in the pipeline or level top ditch eliminate the need. Large streams of water can be handled with very little labor at high efficiencies with this type of distribution system.

By choosing the best adapted method and operating it correctly, by checking the soil moisture deficiency and comparing it to the Management Allowed Deficiency to determine when to irrigate, and then by turning the water off when enough has been infiltrated, one can obtain very efficient irrigation.

By having a system with a large enough capacity to keep an irrigator economically busy, and one that is easy to use, labor costs can be kept low.

If one has these things one can have efficient irrigation and plant more land with less water.

APPENDIX

Glossary

Management Allowed Deficiency (MAD) is the soil moisture deficiency in the root zone at which management anticipates the economically optimum condition. It is first expressed as a percent of the available moisture in the root zone corresponding to the desired maximum stress in the plant. It is then converted to the corresponding inches of soil moisture deficiency in the root zone which is the desired depth of water to be applied.

Soil Moisture Deficiency (SMD) is the depth of moisture (dryness) that has been removed from the root zone at any particular moment. It is the maximum that can be replaced and stored in the root zone. It can also be expressed as the deficiency in a unit depth of soil, e.g., inches deficient/foot of soil.

Time of Irrigation (T_i) is the duration that is needed to infiltrate the desired depth of water at a point.

Time of Application (T_a) is the duration that water is being applied to the field.

Time of Advance (T_{adv}) is the duration needed for the stream to move across the field.

Time of Opportunity (T_o) is how long water was on the surface with opportunity to infiltrate the soil.

Time of Lag (T_L) is how long the water remains at the upper end of a field after it has been turned off.

Advance Ratio (AR) is the ratio of the Time of Advance to the Time of Opportunity at the far end of a furrow or field and which ideally is T_i.

Cumulative Depth Infiltrated Curve is a plotting of the depth of water that entered the soil after any increment of time. It usually plots a straight line on logarithmic paper.

Depth Infiltrated Curve is a plotting of the depth of water that has penetrated the soil at various places across a field, or an extension of it.

Advance Curve is a plotting of when the moving water arrives at various places across a field, or an extension of it.

Recession Curve is a plotting of when water disappears from various places across a field, or an extension of it. The time difference between it and the Advance Curve is the duration (Time of Opportunity) that water is at any point.

Irrigation Curve is a plotting of when water should disappear from various places across a field. It is plotted parallel to the Advance Curve and above it by the Time of Irrigation.

(In the following three equations, the minimum depth is the average depth in the quarter of the area receiving the lowest amount. ie. about one eighth of the area is slightly under-irrigated.)

Potential Application Efficiency (PAE) is the ratio of the minimum depth of water stored when that just equals the soil moisture deficiency (SMD) to the average depth of water applied. It is the measure of how well the system can do the job.

$$\text{PAE} = \frac{\text{min. depth stored} = \text{SMD}}{\text{av. depth applied when the SMD is just satisfied}}$$

Actual Application Efficiency (AAE) is the ratio of the minimum depth of water stored to the average depth of water applied. The minimum depth stored cannot exceed the SMD but may be less. It is a measure of how well a system is being used.

$$\text{AAE} = \frac{\text{min. depth stored}}{\text{av. depth applied}}$$

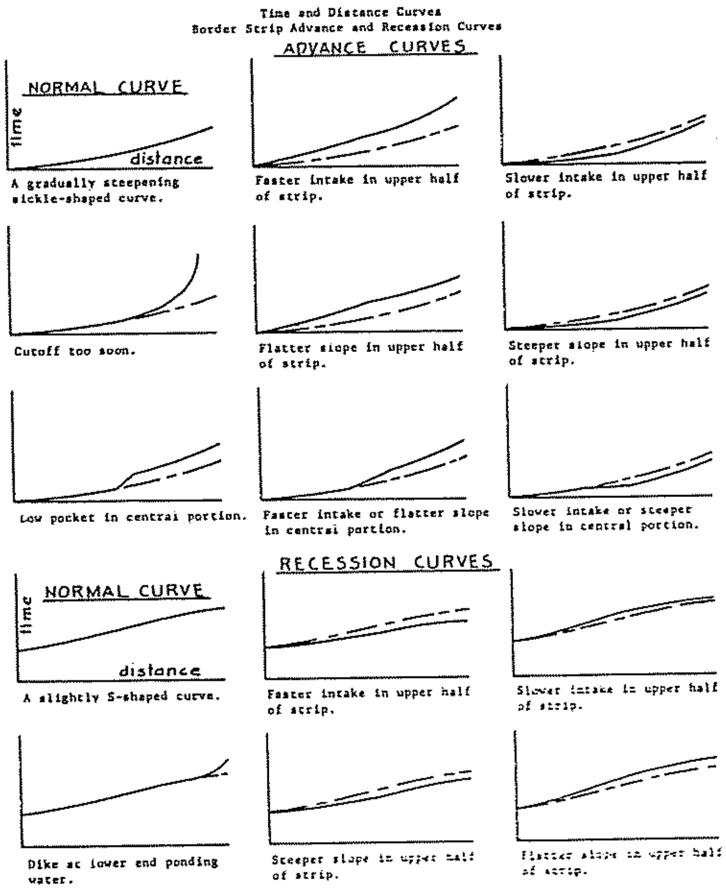
Distribution Uniformity (DU) is the ratio of the minimum depth of water infiltrated to the average depth of water infiltrated.

Minimum Depth is the average of the one fourth of the total area that receives the least water. Approximately one eighth of the total area will receive from zero to slightly less than this minimum value.

Coefficient of Uniformity (C_u) is the ratio of the average depth infiltrated minus the average deviation from this average depth (or caught in sprinkler tests) to the average depth.

$$C_u = \frac{\text{av. depth infiltrated - av. deviation}}{\text{av. depth infiltrated}}$$

Figure 8


Time and Distance Curves
Border Strip Advance and Recession Curves
ADVANCE CURVES
NORMAL CURVE
time
distance
A gradually steepening sickle-shaped curve.
Faster intake in upper half of strip.
Slower intake in upper half of strip.
Cutoff too soon.
Flatter slope in upper half of strip.
Steeper slope in upper half of strip.
Low pocket in central portion.
Faster intake or flatter slope in central portion.
Slower intake or steeper slope in central portion.
RECESSION CURVES
NORMAL CURVE
time
distance
A slightly S-shaped curve.
Faster intake in upper half of strip.
Slower intake in upper half of strip.
Dike at lower end ponding water.
Steeper slope in upper half of strip.
Flatter slope in upper half of strip.

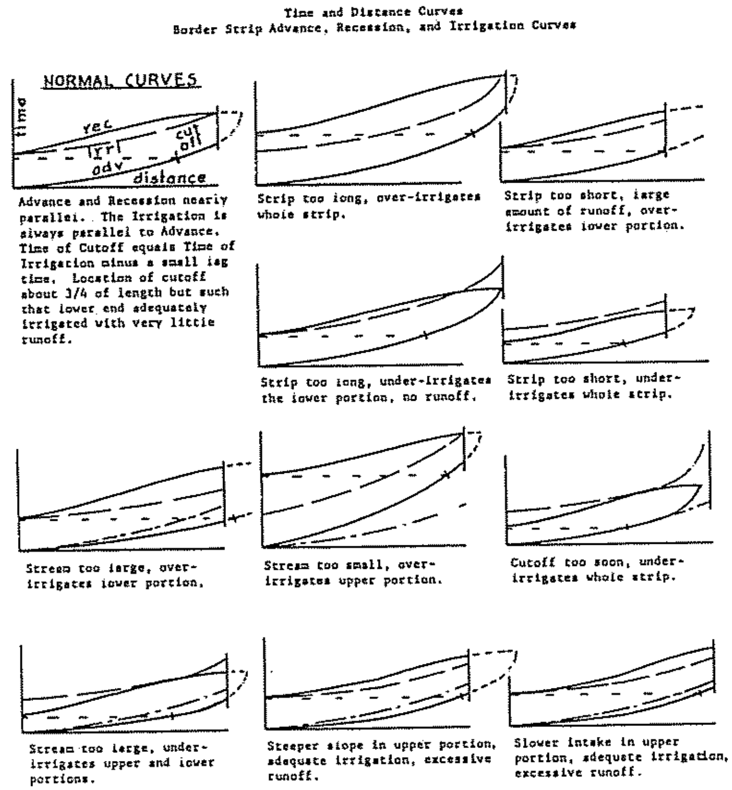

Time and Distance Curves
Border Strip Advance, Recession, and Irrigation Curves
NORMAL CURVES
time
rec
irri
adv
cut off
distance
Advance and Recession nearly parallel. The Irrigation is always parallel to Advance. Time of Cutoff equals Time of Irrigation minus a small lag time. Location of cutoff about 3/4 of length but such that lower end adequately irrigated with very little runoff.
Strip too long, over-irrigates whole strip.
Strip too short, large amount of runoff, over-irrigates lower portion.
Strip too long, under-irrigates the lower portion, no runoff.
Strip too short, under-irrigates whole strip.
Stream too large, over-irrigates lower portion.
Stream too small, over-irrigates upper portion.
Cutoff too soon, under-irrigates whole strip.
Stream too large, under-irrigates upper and lower portions.
Steeper slope in upper portion, adequate irrigation, excessive runoff.
Slower intake in upper portion, adequate irrigation, excessive runoff.

Figure 7

SOIL MOISTURE DEFICIENCY AND APPEARANCE RELATIONSHIP CHART

This chart indicates approximate relationship of soil moisture deficiency between field capacity and wilting point.
For more accurate information the soil must be checked by drying samples.

Moisture Deficiency in./ft.	SOIL TEXTURE CLASSIFICATION Coarse (loamy sand)	Sandy (sandy loam)	Medium (loam)	Fine (clay loam)	Moisture Deficiency in./ft.
.0	(field capacity) Leaves wet outline on hand when squeezed.	(field capacity) Appears very dark, leaves wet outline on hand, makes a short ribbon.	(field capacity Appears very dark, leaves a wet outline on hand, will ribbon out about one inch.	(field capacity) Appears very dark, leaves slight moisture on hand when squeezed, will ribbon out about two inches.	.0
.2	Appears moist, makes a weak ball.	Quite dark color, makes a hard ball.	Dark color, forms a plastic ball, slicks when rubbed.		.2
.4	Appears slightly moist sticks together slightly.			Dark color, will slick and ribbons easily	.4
.6		Fairly dark color, makes a good ball.	Quite dark, forms a hard ball.	Quite dark, will make thick ribbon, may slick when rubbed.	.6
.8	Dry, loose, flows thru fingers. (wilting point)	Slightly dark color. makes a weak ball.	Fairly dark, forms a good ball.		.8
1.0		Lightly colored by moisture, will not ball.		Fairly dark, makes a good ball.	1.0
1.2		Very slight color due to moisture. (wilting point)	Slightly dark, forms weak ball.	Will ball, small clods will flatten out rather than crumble.	1.2
1.4			Lightly colored, small clods crumble fairly easily.	Slightly dark, clods crumble.	1.4
1.6			Slight color due to moisture, small clods are hard. (wilting point)		1.6
1.8				Some darkness due to unavailable moisture, clods are hard, cracked. (wilting point)	1.8
2.0					2.0

Field Method of Approximating Soil Moisture (Deficiency) for Irrigation; Transactions of the American Society of Agricultural Engineers, Vol. 3, No. 1, 1960; John L. Merriam, Professor, California Polytechnic State University, San Luis Obispo, California.

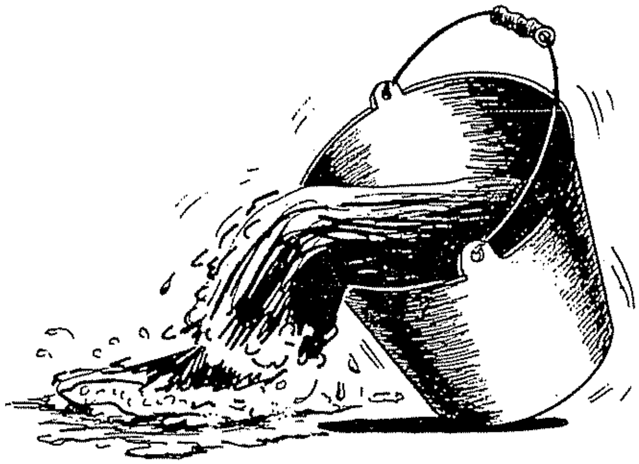
1975

9-4

DROUGHT

TIPS

HOW MUCH IRRIGATION WATER ARE YOU APPLYING?



It's very hard to irrigate efficiently without knowing how much water you're putting on. Often crop water requirements are expressed in inches. How do you get from gallons per minute to inches? Following is information pertaining to just that, along with answers to other common questions concerning "How Much".

More detailed technical assistance is available from the local representatives of the Soil Conservation Service, University of California Cooperative Extension Service, Bureau of Reclamation, irrigation or resource conservation districts, Department of Water Resources, irrigation equipment representatives or irrigation consultants.

PROCEDURE FOR CALCULATING DEPTH OF WATER APPLIED

STEP I

	SYSTEM				
	FURROWS		BORDERS/BASINS	SPRINKLERS	CENTER PIVOT
AREA IRRIGATED (Acres)	AREA = $\frac{\text{(NO. OF FURROWS)} \times \text{(SPACING IN FEET)} \times \text{(LENGTH IN FEET)}}{(43{,}560)}$		(A) AREA PER BORDER = $\frac{\text{(LENGTH IN FEET)} \times \text{(WIDTH IN FEET)}}{(43{,}560)}$ (B) TOTAL AREA (ACRES) = (NO. OF BORDERS) X (AREA PER BORDER)	AREA = $\frac{\text{(LATERAL LENGTH IN FEET)} \times \text{(MOVE IN FEET)}}{(43{,}560)}$	AREA PER CENTER PIVOT = $\frac{(.0314) \times \left[\text{LATERAL LENGTH IN FEET}\right]^2 \times \text{(P IN \%)}}{(43{,}560)}$ WHERE: P = PERCENT OF FULL CIRCLE

STEP II

	SIPHONS		PUMPS	SPRINKLER	VERTICAL PIPE
FLOW – GALLON PER MINUTE (GPM)	(A) SEE TABLE 1 FOR "GPM PER SIPHON" (B) TOTAL FLOW = $\left[\text{NO. OF SIPHONS}\right] \times \left[\text{GPM PER SIPHON}\right]$		SEE TABLE 2 FOR GPM FLOW FROM PUMP	(A) SEE TABLE 3 FOR "GPM PER SPRINKLER" (B) TOTAL FLOW = $\left[\text{NO. OF SPRINKLERS}\right] \times \left[\text{GPM PER SPRINKLER}\right]$	SEE TABLE 4 FOR GPM FROM VERTICAL PIPES

STEP III

DEPTH OF WATER APPLIED (Inches)	USE TOTAL FLOW FROM (II) ABOVE WITH TABLE 5 AND YOUR SET TIME TO GET ACRE INCHES OF WATER APPLIED. DEPTH APPLIED (INCHES) = $\frac{\text{(ACRE INCHES OF WATER APPLIED)}}{\text{(AREA IRRIGATED FROM I ABOVE)}}$

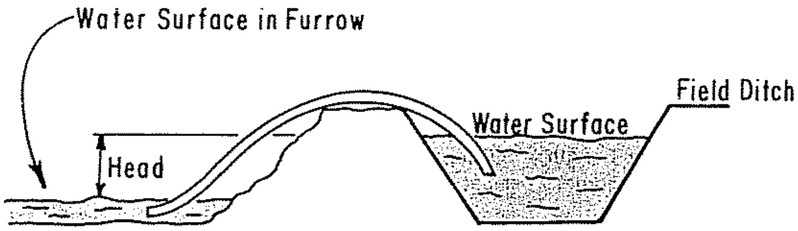


TABLE 1

SIPHON TUBE DISCHARGE – (GPM)

DIAMETER OF SIPHON (Inches)	2''* HEAD	3'' HEAD	4'' HEAD	6'' HEAD	9'' HEAD
3/8	.7	1.0	1.2	1.5	1.7
1/2	1.3	1.6	1.8	2.1	2.7
3/4	3	4	5	6	7
1	5	6	7	9	11
1-1/4	8	10	12	15	18
1-3/8	10	13	15	19	23
1-1/2	13	16	18	24	28
2	21	27	32	41	50
2-1/2	32	40	48	54	65
3	46	57	65	82	100
4	86	106	122	153	200

*HEAD IS DIFFERENCE IN HEIGHT OF WATER IN SUPPLY DITCH AND CENTER OF DISCHARGE END OF TUBE OR WATER SURFACE TO WATER SURFACE IF TUBE OUTLET IS SUBMERGED.

$$\text{NUMBER OF FURROWS} = \frac{\text{Q - GPM STREAM}}{\text{q - GPM OF SIPHON TUBES}}$$

HORIZONTAL PIPE DISCHARGE (GPM)

(pipe flowing full)

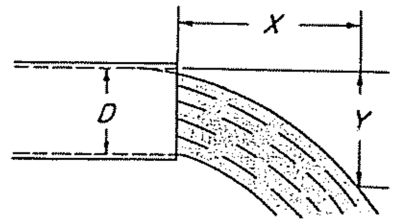


TABLE 2

WHEN X = 12 INCHES

Y (INCHES)	D = INSIDE DIAMETER OF PIPE 4-INCH	6-INCH	8-INCH	10-INCH	12-INCH	14-INCH	16-INCH
2	419	1044	2005	3312	4969	6977	9339
4	294	724	1386	2288	3435	4829	6471
6	238	580	1106	1826	2742	3859	5177
8	204	493	937	1545	2322	3271	4394
10	181	433	819	1350	2031	2864	3851
12	164	387	731	1204	1812	2559	3445
14	150	352	662	1089	1641	2319	3126
16	139	323	605	996	1500	2123	2865
18	130	299	558	917	1383	1959	2647
20	122	278	517	850	1283	1819	2461

WHEN X = 18 INCHES

Y (INCHES)	D = INSIDE DIAMETER OF PIPE 4-INCH	6-INCH	8-INCH	10-INCH	12-INCH	14-INCH	16-INCH
2	601	1421	2713	4508	6819	9652	13011
4	423	999	1897	3144	4750	6721	9060
6	345	811	1532	2532	3820	5403	7285
8	298	698	1313	2163	3259	4608	6213
10	265	621	1161	1908	2871	4058	5472
12	242	563	1049	1718	2582	3648	4919
14	223	519	960	1569	2355	3325	4485
16	208	482	888	1447	2170	3063	4132
18	196	452	829	1346	2015	2844	3836
20	185	426	777	1259	1883	2656	3584

WHEN X = 24 INCHES

Y (INCHES)	D = INSIDE DIAMETER OF PIPE 4-INCH	6-INCH	8-INCH	10-INCH	12-INCH	14-INCH	16-INCH
2	806	1815	3373	5569	8434	11983	16226
4	565	1281	2375	3909	5907	8384	11345
6	458	1044	1931	3168	4778	6773	9159
8	393	903	1665	2723	4099	5803	7843
10	348	806	1483	2418	3632	5135	6936
12	315	735	1348	2191	3284	4638	6261
14	290	679	1242	2014	3012	4249	5731
16	269	634	1157	1870	2791	3932	5301
18	251	597	1086	1750	2607	3668	4942
20	236	565	1026	1648	2450	3443	4635

TABLE 3
SPRINKLER NOZZLE DISCHARGE (GPM)

NOZZLE SIZE (In.)	25	30	35	40	45	50	55	60	65	70	75	WETTED DIAMETER 1/
												60'
3/32	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0				70'
7/64	1.7	1.9	2.0	2.2	2.3	2.4	2.6	2.7				80'
1/8	2.2	2.4	2.6	2.8	3.0	3.2	3.3	3.5	3.6			
9/64	2.9	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6			90'
5/32	3.5	3.9	4.2	4.5	4.7	5.0	5.2	5.5	5.7	5.9		
11/64	4.3	4.7	5.1	5.4	5.7	6.0	6.3	6.6	6.8	7.1		
3/16	5.0	5.5	6.0	6.4	6.8	7.2	7.5	7.8	8.1	8.4	8.7	100'
13/64	5.9	6.5	7.1	7.6	8.1	8.5	8.9	9.2	9.5	9.8	10.2	
7/32	6.8	7.6	8.3	8.9	9.4	9.9	10.3	10.7	11.2	11.6	12.0	110'
1/4		9.9	10.7	11.4	12.1	12.8	13.5	14.1	14.8	15.4	16.0	125'
9/32		12.4	13.4	14.3	15.2	16.1	17.0	17.9	18.7	19.5	20.3	
5/16		15.2	16.5	17.7	18.9	20.0	21.0	22.0	23.0	23.9	24.8	145'
11/32			19.7	21.1	22.4	23.6	24.8	25.9	27.0	28.1	29.2	
3/8			22.8	24.4	26.0	27.6	29.2	30.6	32.0	33.3	34.5	
13/32			27.2	29.1	30.9	32.7	34.3	35.9	37.4	38.9	40.3	165'
7/16				33.9	35.9	37.8	39.7	41.5	43.3	45.1	46.8	
15/32				38.9	41.1	43.3	45.4	47.4	49.4	51.4	53.3	185'
1/2				43.6	46.0	48.4	50.7	53.0	55.3	57.2	59.6	
17/32					51.6	54.0	56.4	58.8	61.2	63.5	65.8	205'
9/16					57.5	60.6	63.6	66.5	69.4	72.2	74.9	
5/8					70.0	73.6	77.2	80.8	84.4	87.8	91.0	

1/ APPROXIMATE DIAMETER OF COVERAGE. FOR SPRINKLER WITH 2 DIFFERENT NOZZLES, THE WETTED DIAMETER IS COVERAGE OF THE LARGER NOZZLE.

TABLE 4
VERTICAL PIPE DISCHARGE (GPM)

JET HEIGHT (INCHES) H	D = DIAMETER OF PIPE (Inches)													
	2 STD. 2/	3 STD.	4 O.D. 3/	4 STD.	5 O.D.	5 STD.	6 O.D.	6 STD.	8 O.D.	8 STD.	10 O.D.	10 STD.	12 O.D.	12 STD.
	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.	G.p.m.
2	28	57	75	86	103	115	137	150	200	215	265	285	330	355
2-1/2	31	69	95	108	132	150	182	205	275	290	357	385	450	480
3	34	78	112	128	160	183	225	250	340	367	450	490	570	610
3-1/2	37	86	124	145	183	210	262	293	405	440	555	610	705	755
4	40	92	135	160	205	235	295	330	465	510	660	725	845	910
4-1/2	42	98	144	173	225	257	320	365	520	570	760	845	980	1060
5	45	104	154	184	240	275	345	395	575	630	840	940	1120	1200
6	50	115	169	205	266	306	385	445	670	730	1000	1125	1370	1500
7	54	125	186	223	293	336	420	485	750	820	1150	1275	1600	1730
8	58	134	202	239	315	360	450	520	810	890	1270	1420	1775	1950
9	62	143	215	254	335	383	480	550	870	955	1360	1550	1930	2140
10	66	152	227	268	356	405	510	585	925	1015	1450	1650	2070	2280
12	72	167	255	295	390	450	565	650	1010	1120	1600	1830	2300	2550
14	78	182	275	320	420	485	610	705	1100	1220	1730	2000	2530	2800
16	83	195	295	345	455	520	635	755	1180	1300	1870	2140	2720	3000
18	89	208	315	367	480	555	700	800	1265	1400	2000	2280	2900	
20	94	220	333	388	510	590	740	850	1335	1480	2100	2420		
25	107	248	377	440	580	665	830	960	1520	1670	2380	2720		
30	117	275	420	485	640	740	925	1050	1690	1870	2650	3000		
35	127	300	455	525	695	800	1000	1150	1820	2020	2850			
40	137	320	490	565	745	865	1075	1230	1970	2160				

1/ TABLE PREPARED FROM DISCHARGE CURVES IN UTAH ENGIN. EXPT STA. BUL. 5. "MEASUREMENT OF IRRIGATION WATER," JUNE 1955.

2/ STANDARD PIPE.

3/ OUTSIDE DIAMETER OF WELL CASING.

TABLE 5
CONVERSION TABLE – GPM AND CFS TO ACRE INCHES OF WATER APPLIED

GPM	CFS	SET TIME – HOURS 6	7	8	9	10	11	12	14	16	18	20	24	36	48
45	.1	.6	.7	.8	.9	1.0	1.1	1.2	1.4	1.6	1.8	2.0	2.4	3.6	4.8
90	.2	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.8	3.2	3.6	4.0	4.8	7.2	9.6
135	.3	1.8	2.1	2.4	2.7	3.0	3.3	3.6	4.2	4.8	5.4	6.0	7.2	10.8	14.4
180	.4	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.6	6.4	7.2	8.0	9.6	14.4	19.2
225	.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	9.0	10.0	12.0	18.0	24.0
270	.6	3.6	4.2	4.8	5.4	6.0	6.6	7.2	8.4	9.6	10.8	12.0	14.4	21.6	28.8
315	.7	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.8	11.2	12.6	14.0	16.8	25.2	33.6
360	.8	4.8	5.6	6.4	7.2	8.0	8.8	9.6	11.2	12.8	14.4	16.0	19.2	28.8	38.4
405	.9	5.4	6.3	7.2	8.1	9.0	9.9	10.8	12.6	14.4	16.2	18.0	21.6	32.4	43.2
450	1.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	14.0	16.0	18.0	20.0	24.0	36.0	48.0
495	1.1	6.6	7.7	8.8	9.9	11.0	12.1	13.2	15.4	17.6	19.8	22.0	26.4	39.6	52.8
540	1.2	7.2	8.4	9.6	10.8	12.0	13.2	14.4	16.8	19.2	21.6	24.0	28.8	43.2	57.6
585	1.3	7.8	9.1	10.4	11.7	13.0	14.3	15.6	18.2	20.8	23.4	26.0	31.2	46.8	62.4
630	1.4	8.4	9.8	11.2	12.6	14.0	15.4	16.8	19.6	22.4	25.2	28.0	33.6	50.4	67.2
675	1.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	21.0	24.0	27.0	30.0	36.0	54.0	72.0
720	1.6	9.6	11.2	13.0	14.4	16.0	17.6	19.2	22.4	25.6	28.8	32.0	38.4	57.6	76.8
765	1.7	10.2	11.9	13.6	15.3	17.0	18.7	20.4	23.8	27.2	30.6	34.0	40.8	61.2	81.6
810	1.8	10.8	12.6	14.4	16.2	18.0	19.8	21.6	25.2	28.8	32.4	36.0	43.2	64.8	86.4
855	1.9	11.4	13.3	15.2	17.1	19.0	20.9	32.8	26.6	30.4	34.2	38.0	45.6	68.4	91.2
900	2.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	28.0	32.0	36.0	40.0	48.0	72.0	96.0
990	2.2	13.2	15.4	17.6	19.8	22.0	24.2	26.4	30.8	35.2	39.6	44.0	52.8	79.2	105.6
1080	2.4	14.4	16.8	19.2	21.6	24.0	26.4	28.8	33.6	38.4	43.2	48.0	57.6	86.4	115.2
1170	2.6	15.6	18.2	20.8	23.4	26.0	28.6	31.2	36.4	41.6	46.8	52.0	62.4	93.6	124.8
1260	2.8	16.8	19.6	22.4	26.2	28.0	30.8	33.2	39.2	44.8	50.4	56.0	67.2	100.4	134.4
1350	3.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0	42.0	48.0	54.0	60.0	72.0	108.0	144.0

NOTES

REFERENCES

1. Irrigation, Section 15, National Engineering Handbook, Soil Conservation Service, USDA

FOR FURTHER INFORMATION CONTACT:

Agricultural Research Service
Department of Water Resources
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State Water Resources Control Board
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U.S. Bureau of Reclamation
U.S. Geological Survey

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